NASA Technical Memorandum 106142

IN-18
167258
p-14

Battery Selection for Space Shuttle Experiments

David R. Francisco
Lewis Research Center
Cleveland, Ohio

April 1993

(NASA-TM-106142) BATTERY SELECTION FOR SPACE SHUTTLE EXPERIMENTS (NASA) 14 p

N93-27038

Unclas

G3/18 0167258

NASA

BATTERY SELECTION FOR SPACE SHUTTLE EXPERIMENTS

David R. Francisco
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

This paper will delineate the criteria required for the selection of batteries as a power source for space experiments. Four basic types of batteries will be explored, lead acid, silver zinc, alkaline manganese and nickel cadmium. A detailed description of the lead acid and silver zinc cells while a brief exploration of the alkaline manganese and nickel cadmium will be given. The factors involved in battery selection such as packaging, energy density, discharge voltage regulation, and cost will be thoroughly examined. The pros and cons of each battery type will be explored. Actual laboratory test data acquired for the lead acid and silver zinc cell will be discussed. This data will include discharging under various temperature conditions, after three months of storage and with different types of loads. The lifetime and number of charge/discharge cycles will also be discussed. A description of the required maintenance for each type of battery will be investigated.

Space Experiment Battery Selection Overview

When designing a space experiment (for the purpose of this paper a space experiment is defined as hardware that is flown on the shuttle or any other vehicle that provides a platform for microgravity research) one of the primary concerns is the power source for the experiment. If a battery is selected, many factors contribute to this selection. Complete load characteristics, power requirements, energy requirements, and storage period must be considered in order to choose the correct battery. The available weight, volume restrictions and the environment in which the experiment will be operated is also critical in determining the correct battery for a space experiment.

Other factors that contribute to the selection of a battery is the location in which the experiment will operate. If the experiment will operate in an inhabited environment, then additional precautions must be taken. The cost of the battery and the maintenance required also plays a major role in selection of a battery. In this paper all of these factors will be considered in the description of each battery type.

Battery Terminology

Before a detailed description of each battery type can be started, an understanding of battery terminology is necessary. The following sections explain the relevant terms needed in understanding the application of batteries.

Capacity

The capacity (C) of a battery is usually defined as the number of amp-hours that a fully charged cell can supply. The capacity is affected by the rate at which the battery will be discharged, the temperature of the battery when discharging, and the state of charge. The capacity listed on a battery is valid only when the the battery is discharged at 1/10 (C/10) of the listed amp-hours (i.e. a 15 amp-hour battery discharged at 1.5 amps for 10 hours). If the battery is discharged at a faster rate, the capacity will significantly decrease. Different types of batteries perform better at higher discharge rates than others, this will be discussed in each of the battery type descriptions.

Cycle

A cycle on a battery is one sequence of charging and discharging. Only secondary batteries have cycles.

Charging

The process of returning electrical energy to a battery. Secondary cells require charging.

Discharge Voltage Regulation

Discharge voltage regulation is defined as the stability of the batteries voltage during discharge. Some batteries, such as lead acid cells, will slowly decrease in voltage as they are discharged until the voltage drops quickly at the end of capacity. Other cells such as silver zinc cells will remain at one voltage level for a majority of the discharge cycle, then it will drop dramatically.

Depth of Discharge (DOD)

This is the percent of the capacity discharged in relation to rated capacity from a battery.

Electrolyte

Electrolyte is the medium used to transport ions within the battery.

Energy

Energy is the total amount of power delivered by the battery over time. This is calculated by taking the capacity (amp hours) times the average discharge voltage (= watt-hours).

Open Circuit Voltage (OCV)

The OCV of a battery is voltage measured when no load is applied to the battery. Measurement of the OCV is an indicator of the state of charge for many types of batteries.

Power

Power is defined as the number of watts discharged from a battery at a specific instance in time (such as the peak power was 150 watts).

Primary Battery

A primary battery can not be charged and is only used once.

Sealed Cells

Sealed cells do not require maintenance and are usually equipped with a high pressure vent. Most of these types of cells contain the minimal amount of electrolyte (see the section on Lead Acid Cells).

Secondary Battery

A secondary battery is one that can be recharged to the original full capacity. This type of battery is rated for the maximum number of charge/discharge cycles.

Self-Discharge Rate

Self-discharge rate is the rate at which a battery (or cell) loses capacity while standing idle (in storage). This rate is affected by the temperature at which the battery is stored. This parameter is critical when selecting a type of battery for a space experiment.

This concludes the discussion of battery terminology. The following sections will discuss the use of lead acid, silver zinc, alkaline manganese and nickel cadmium cells with respect to space experiments.

Sealed Lead Acid (SLA) Cells

Description

Lead acid cells are secondary cells that are commonly used in the automotive industry. The cells used in autos have a liquid electrolyte (H_2SO_4 - sulfuric acid), where as the cells considered for space experiments are sealed lead acid cells (SLA). The SLA cells have a minimum amount of electrolyte and are maintenance free because they operate on a gas recombination principle (the oxygen and most of the hydrogen generated within the cell are recombined, therefore no additional water is needed - See Figure 1.0). The anode is made of lead and the cathode consist of lead dioxide (PbO_2). The cases are made of metal (isolated) and are sealed with a resealable pressure valve.

Capacity

Lead acid cells have a low internal resistance (on the order of 5 mΩ) which allows the cells to source high current. A 12.5 amp-hour cell (rating at C/10 discharge rate) is capable of delivering 9.0 Amp-hours when discharged at 12.5 Amp/hour rate (1C). In comparison to most other batteries SLA cells are much heavier for the same capacity.

Cycles

The number of cycles that can be obtained from a lead acid cell can vary between 200 to 2,000 depending on the use of the cell. The two factors that affect the life are the depth of discharge and the charging method. If the cells are discharged 100% during each cycle and charged without a current limit, then the life will end at about 200 cycles. If the cell is only discharged 25% and charged with a current limit of 2 Amps the life will be closer to 2,000 cycles.

Storage

Stored SLA cells should be trickle charged with a voltage approximately 2.25V to 2.30 V per cell. If the cells are not trickle charged, then they will loose capacity during storage. At room temperature the specifications indicate that these cells will loose 20% of their capacity after 6 months. Test data reveals that SLA cells stored at room temperature decreased in capacity by 35% after 5 1/2 months. At lower temperatures the cells will retain more capacity.

Temperature Performance

Lead acid cells perform better than other types of cells at lower temperatures. As per the specifications of sealed lead acid cells, a 15% reduction in energy is seen at a temperature of 0 C for a discharge rate of C/10. If the cells are discharged at a rate of 1.2C the reduction energy is approximately 35 %. A battery made of 16 cells with a capacity of 12.5 Amp hours was discharged at 32 F. These cells were discharged at a C/6 rate. Approximately a 8 % reduction of energy from a room temperature discharge was documented during this test.

Voltage Characteristics

The discharge voltage of lead acid cells varies from approximately 2.15 volts when fully charged to 1.6 volts when discharged (end of capacity). The temperature at which the discharge occurs will affect the discharge voltage. At 0 C the discharge voltage will be slightly (0.05 volts) lower.

Maintenance

These cells required very little maintenance. No additional electrolyte has to be added during the life of the cells. Charging of the cells requires a current limited constant voltage source between 2.4-2.6 Volts per cell. Standard battery chargers may be readily purchased. Determining the state of charge of SLA cells is easily achieved by taking the open circuit voltage (OCV) and substituting this voltage in the following equation: % charge = (OCV-1.98V)500. The only characteristics of the cells that require additional maintenance is that these cells need to be cycled (discharged deeply -90% of rated capacity) after an extended storage in order to achieve full capacity.

Packaging

Packaging requires minimal provisions. These cells do have a resealable pressure valve, but they seldom vent while discharging. During normal operation the O_2 and H_2 is recombined and no venting occurs. The conditions that cause venting is overcharging or if non-current limiting charging occurs. The main concern is the buildup of concentrated O_2 and H_2. The cell terminals and electrical connector must be coated with epoxy to prevent accidental shock and protection from any H_2SO_4 that may be vented. If these cells are used properly they could be a good candidate to use in an inhabited environment.

SLA Conclusion

SLA cells are very inexpensive, require very little maintenance and can withstand many cycles. The voltage regulation and the storage charge capacity retention is average. The major disadvantage of these cells is the weight and volume required to obtain the desired energy. Relative to other battery types, these cells require the most weight and volume to achieve the same capacity. Therefore if minimal energy (< 300 watt hours) is required and considerable weight and volume is available (30Kg and .36 m^2) then SLA cells should be considered.

Silver Zinc

Description

Silver zinc cells are secondary cells that are usually used in military and aerospace applications. Silver zinc cells have a liquid electrolyte of potassium hydroxide (KOH) with the negative electrode of zinc and the positive electrode as silver. For space experiment applications the cell has a resealable vent valve. The case is made of a styrene plastic that is very durable.

These cells are purchased "dry, uncharged" or "dry, charged." Either type requires filling the cells with electrolyte. The dry uncharged cells require a formation process (see the maintenance section) and the dry charged cells may be used immediately after the filling of electrolyte. Both types of cells have the same characteristics, which are described in the following sections.

Capacity

Silver zinc cells have a low internal resistance (on the order of 3.5 mΩ) which allows the cells to source high current. A 15 Amp-hour cell is rated at 20 Amp-hours when discharged at C/10 at the beginning of life. The capacity at C/3 rate was tested at the beginning of life (initial cycle), a 15 amp hour cell supplied approximately 20 amp hours. Subsequent cycles showed a slight decrease (10%) in capacity. In comparison to most other batteries silver zinc cells are much lighter and much more energy dense (5 times greater than SLA cells). A characteristic of silver zinc cells that are discharged at a very low rate (approximately 40 hours or more) is that the cells have a tendency to loose capacity on subsequent cycles (approximately 10 to 25%). This capacity can usually be recovered after charging at the same rate as the slow discharge.

Cycles

The number of cycles that can be obtained from a silver zinc cell can vary between 100 to 200 or more depending on the use of the cell. The major factors that affect the life are the depth of discharge, maintenance and storage conditions.

Storage

Silver zinc cells may be stored in the dry state (no electrolyte) for at least five years in a dry environment. Once the cells are wetted (filled with electrolyte), the active life is usually 1 to 2 years depending on the number of cycles.

Once the cells are wetted and charged, they are specified to retain 85% of their capacity when stored at room temperature for 3 months. Testing has verified this specification.

Temperature Performance

Silver zinc cells do not perform as well as lead acid cells at lower temperatures. As per the specifications of silver zinc cells, a 20% reduction in energy is seen at a temperature of 0 C for a discharge rate of C/10. Testing of a 19 cell 15 amp-hour battery at 0 C indicated a 18% reduction in capacity.

Voltage Characteristics

The discharge voltage characteristic of silver zinc cells is a dual plateau (two separate and distinct voltage levels during discharge). The first plateau is 1.75 volts/cell for approximately 20% to 30% of capacity and for the remainder of the capacity the voltage is at 1.5 volts/cell. Once the second plateau is reached the voltage is very stable for silver zinc cells.

Maintenance

These cells required a considerable amount of maintenance. Initially the cells must be filled with electrolyte which requires safety precautions (KOH is a caustic) and is time consuming. If the uncharged cells are used, then a formation process is required. This process requires the cells to be charged initially and then discharged at a C/3 rate. If the rated capacity is not achieved then the cycle must be repeated. These cells have a resealable vent valve and they do vent during their lifetime. This requires the box that encloses the cells (and any components in contact with the cells such as an electrical connector) to be impervious to KOH. In most cases an epoxy is used to pot the cells with a opening for the vent valve. Charging of the cells requires a constant current with a shutoff of approximately 2 volts per cell. Usually a custom battery charger is required. Some manufacturers produce battery chargers that may be readily used. Determining the approximate state of charge of silver zinc cells from their open circuit voltage (OCV) may be done. The OCV will tell if the cells are greater than 70% capacity (cell voltage approximately 1.85 V) or less than 70% (cell voltage approximately 1.6 volts).

Packaging

Packaging requires additional provisions. Since the cells are equipped with vent valves, precautions must be taken to limit the possible contact of the electrolyte (KOH) with the surroundings (battery box). The battery box must be sealed and made of a material impervious to KOH. The sealed battery box must be vented (to prevent over pressurization and buildup of concentrated O_2 and H_2), therefore the KOH must be filtered so that no external surface will be in contact with the KOH. In figure 2.0, the fiberglass material used to filter the KOH can be seen. The cell terminals and electrical connector must also be coated with an epoxy impervious to KOH so that electrical contact (including preventing accidental shock) can not be made between the terminals by the vented KOH. These cells would not be a good candidate to use in a inhabited environment.

Silver Zinc Conclusion

Silver zinc cells are expensive, require considerable maintenance, and can withstand a limited number of cycles. The voltage regulation and the storage charge capacity retention is excellent. The major disadvantages to these cells is the maintenance required, packaging and the cost. Relative to other battery types, these cells require the least weight and volume to achieve the same capacity. Therefore if weight and volume is a concern and considerable energy is required, silver zinc cells should be considered.

Alkaline Manganese Dioxide

Description

Alkaline cells are primary cells that are used for most household electronic appliances. The type of alkaline most widely used is alkaline manganese dioxide ($Zn\text{-}MnO_2$). These cells utilize zinc as the anode and manganese dioxide as the cathode and potassium hydroxide as the electrolyte. These cells are cylindrical and the case is usually made of steel.

Electrical Characteristics

Alkaline cells have an internal resistance of less than 1 Ω and are suited for low current draw over a long period of time. A nominal D-cell will deliver 0.8 amps for 15 hours. The starting voltage will be 1.5 volts/cell and its end of life will be at approximately 1.0 volts/cell. The charge retention after storage for alkalines is excellent and is not a concern when used for space experiments. These cells are specified to retain less than 75% of their capacity at 0 C. The overall cost is low and the maintenance required is minimal.

Alkaline Cell Conclusion

Alkalines offer excellent storage capabilities and are very inexpensive. One disadvantage is that if substantial amounts of current (> 1.0 Amps) is required, parallel batteries are needed which adds weight, volume and complexity to the fusing and wiring of the batteries. The voltage regulation during discharge varies significantly and the loads must be able to accommodate this variation. The operation of these cells at lower temperatures is a concern and should be thoroughly tested. Recent changes in the manufacturing of these cells (the mercury content has been lowered) has decreased the capactiy at lower temperatures.

Nickel Cadmium

Nickel cadmium cells are secondary cells that use KOH as the electrolyte, cadmium as the anode and nickel (NiOOH) as the cathode. These cells are commonly used for household electrical appliances that are rechargeable. The case is made of nickel plated steel and is very rugged.

Electrical Characteristics

The internal resistance of nickel cadmium cells is on the order of 15 mΩ. These cells are suited for moderate rates of discharge. Typical cells have a capacity (C) in the range of 1 to 3 amp hours. The discharge voltage ranges from 1.35 volts/cell at full capacity to 1.05 volts/cell at the end of capacity. Nickel cadmium cells lose approximately 1% of capacity per day. The capacity retention due to storage of these cells is not suitable for space experiments.

Nickel Cadmium Conclusion

Even though new higher capacity nickel cadmium cells have been developed, the limiting factor with nickel cadmium for space experiment applications is their storage retention. Since most space experiments are stored for 3 months before flight with no access, nickel cadmium cells would not have sufficient capacity to operate an experiment. Space rated nickel cadmium cells are available (which have lower rates of self discharge) but the cost is inhibiting for most space experiments. Nickel cadmium cells should not be considered for space experiments with an extended storage period.

Conclusion

Table I summarizes the characteristics of each type of battery discussed. The most important consideration when choosing a battery type for a space experiment application is the conditions in which the battery will operate. Details of the loads (power profile) of the experiment, the environment (temperature) of operation, and the available weight, volume and funds available are required to accurately choose the correct battery. Detailed testing under the worst case conditions that the space experiment will experience should also be conducted before choosing a specific battery type. It is also worth noting that there are many other types of batteries that may be used for space experiments.

REFERENCES

1. Battery Energy Data Manual, Whittaker-Yardney Power Systems.

2. Duracell Battery Data Guide For Designers, Duracell U.S.A., Tarrytown, New York, 1981.

3. Duracell Technical Bulletin, Alkaline, Duracell Inc. Bethel, CT, October 1991.

4. Gates Energy Standard Cyclon Battery Catalog, Gates Energy Products, Denver, Colorado, January 1986.

5. Gates Sealed Nickel Cadmium Rechargeable Cells, Gates Energy Products, Gainesville, Florida, October 1987.

BATTERY COMPARSION				
	LEAD ACID	SILVER ZINC	ALKALINES	NICKEL CADMIUM
TYPE	SECONDARY	SECONDARY	PRIMARY	SECONDARY
CAPACITY	2 TO 25 A-HRS	1 TO 600 A-HRS	< 20 A-HRS	< 8 A-HRS
CYCLES	200 TO 2000	100 TO 200	1	500 CYCLES
VOLTAGE REG. /CELL	2.15 - 1.6V	1.7 - 1.5V	1.5 - 1.0V	1.3 - 1.1V
STORAGE CAP RETENTION	3 MON./65%+	3 MON./85%	3 MON./95%+	3 MON./0%
TEMPERATURE CAP AT 0 C	85%	82%(ACTUAL)	50%	90%
MAINTENANCE	MEDIUM	HIGH	LOW	MEDIUM
CONCERNS	WEIGHT	MAINTEN./COST	CURRENT CAP.	STORAGE

Table 1.0

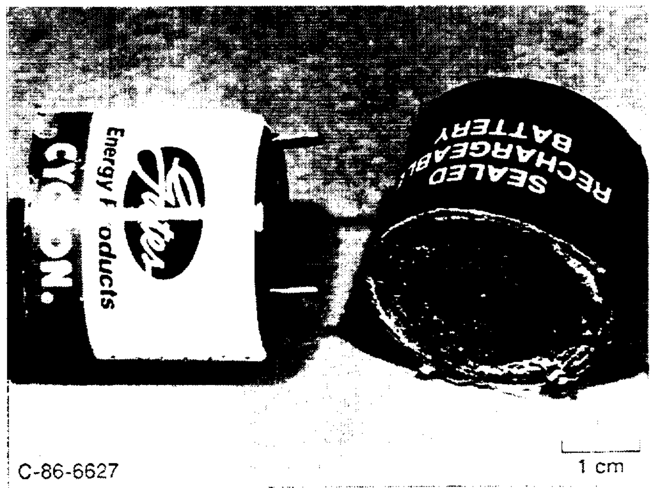

Figure 1.—Sealed lead acid cell cut apart showing gel electrolyte.

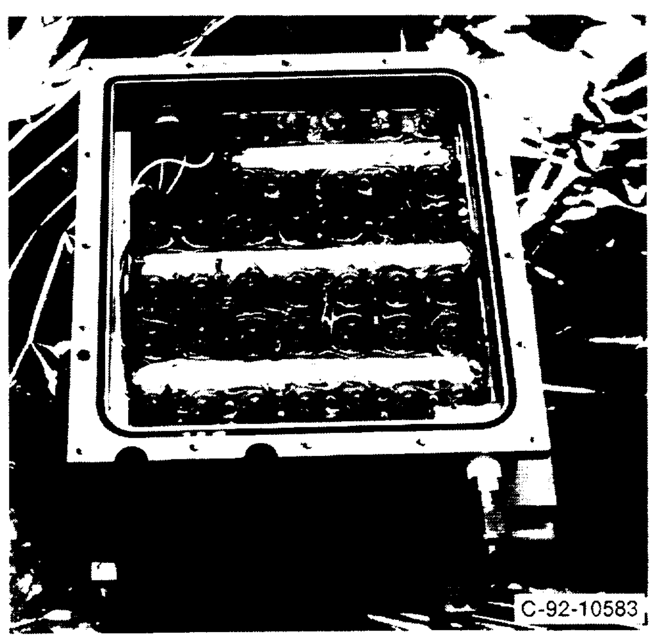

Figure 2.—Silver zinc battery.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
April 1993

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Battery Selection for Space Shuttle Experiments

5. FUNDING NUMBERS
WU-694-03-03

6. AUTHOR(S)
David R. Francisco

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-7822

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-106142

11. SUPPLEMENTARY NOTES
Responsible person, David R. Francisco, (216) 433-2653.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 18

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This paper will delineate the criteria required for the selection of batteries as a power source for space experiments. Four basic types of batteries will be explored, lead acid, silver zinc, alkaline manganese and nickel cadmium. A detailed description of the lead acid and silver zinc cells while a brief exploration of the alkaline manganese and nickel cadmium will be given. The factors involved in battery selection such as packaging, energy density, discharge voltage regulation, and cost will be thoroughly examined. The pros and cons of each battery type will be explored. Actual laboratory test data acquired for the lead acid and silver zinc cell will be discussed. This data will include discharging under various temperature conditions, after three months of storage and with different types of loads. The lifetime and number of charge/discharge cycles will also be discussed. A description of the required maintenance for each type of battery will be investigated.

14. SUBJECT TERMS
Battery selection; Space experiment; Space shuttle

15. NUMBER OF PAGES
14

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102